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A Study on Suitability of Foamed Sandcrete Solid Block with Fly-Ash as Partial Replacement of Sand

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Abstract- In this study, the properties of foamed sandcrete solid block (FSSB) with varying percentage of sand replacement with fly-ash were investigated. These properties include workability, wet and dry density, stability, water absorption capacity and compressive strength. 150mm cube specimens were used for the determination of both the compressive strength and the dry density of the FSSB. The plastic density was investigated using a container of known volume, and its workability determined using the slump test. The fly-ash content was varied from 0 to 50% at interval of 10%. The specimens without the fly-ash served as the control. At the designed density of 1500kg/m^3, the results for the control specimens at 28 day curing age was 3.74N/mm^2. As for 50% sand replacement with fly-ash**,** the compressive strength were 2.37 N/mm, and 3.31 N/mm^2 at 7-days 28-days curing age respectively, both satisfied the minimum compressive strength of 1.8N/mm^2 and 2.5N/mm^2 at the curing age of 7-days and 28-days respectively for conventional sandcrete block for building wall unit as allowed by Nigerian Industrial Standard (N.I.S). The result also shows an appreciable decrease in density of FSSB with 1411.8kg/m^3, as compared to dense sandcrete solid block with average of 1950kg/m^3, which will significantly reduce the overall dead load of the building structure. FSSB with 50% sand replacement with fly-ash also showed a much improved water absorption capacity of 9.81% as control specimen of 11.73%. Fly-ash can be used to reduce the quantity of sand used in FSSB production; thus ridding our environment of potentially harmful wastes, as well as reduce the consumption of non-renewable resources.

Keywords— Foamed Sandcrete, Compressive Strength, fly-ash, dry density, stability, cement

1 INTRODUCTION

Lightweight concrete has been widely used in different structural applications and its consumption grows every year on a global basis. The reason for this is that using lightweight concrete has many advantages. These include: a reduction in dead load of buildings, which minimizes the dimensions of structural members; production of lighter and smaller pre-cast elements with inexpensive casting, handling and transportation operations; provision of more space due to reduction in size of structural members, and increased thermal insulation and fire resistance. In Nigeria, among the multiple construction applications, masonry structures form the largest proportion of the uses of conventional, hollow sandcrete block, which have many drawback (like heavy weight, non-uniform shape and size, low thermal insulation and fire resistance etc.), that can be improved by using lightweight concrete.

Fly ash improves block manufacturing in two basic ways. It gives producers strength required and, at the same time, the added plasticity that fly ash contributes to the relatively harsh block mixes assures improved finish and texture; better mold life, and better, sharper corners (Belot, 1997). Additional benefits of fly ash in block include reduced permeability and shrinkage, increased durability and virtual elimination of efflorescence. Fly ash is produced by burning powdered coal to generate electricity, fly ash is a chemically active, finely divided mineral product high in silica, alumina and iron. Cement sandcrete blocks are versatile masonry materials which can be used in a wide variety of applications. The sandcrete blocks are generally made using sandcrete which is a mixture of Portland cement, sand and water in different specified ratios. Blocks and bricks are widely used in Nigeria as walling units and over 90% of houses in Nigeria are being constructed of blocks; this makes blocks a very important unit in building construction (John and Ban, 2003)**.**

Blocks have been manufactured to meet the need of building demand; this was done without putting into consideration the strength and durability of the blocks (Dhir and Jones, 2009)**.** In building construction, different types of bricks and blocks are used in Nigeria and also in other countries. Structural performances are the most important factors, when using these masonry blocks in constructing walls. However, due to the high cost of materials, the blocks available in the market have fallen below acceptable structural performances by the regulatory body, Nigerian Industrial Standard (NIS). Therefore, it is very important to use innovative materials to reduce cost at least in masonry blocks. Also light-weight materials are becoming much popular nowadays, because of its easy handling and low dead loads (Lim *et al*, 2013)**.** Light-weight masonry blocks with sufficient compressive strength will be a major benefit in building construction. Sand cement blocks are extensively used in Nigeria, because the cement block has benefit in fast assembling the blocks into wall. These blocks are mainly constructed with the cement and fine aggregate with a standard composition. Sandcrete blocks are used extensively for both load bearing and non-load bearing walls, externally and internally. This bring about the need for a light weight sandcrete block, that reduces the accumulate loads on structural elements in building and still fulfill acceptable compressive strength.

2 LITERATURE REVIEW

Sandcrete block is a commonly used building construction material for many centuries. It is a compound material that essentially obtained by mixing the binder (cement), aggregate and water with certain designed proportion. Conventional normal weight sandcrete block is dense, hard, strong and durable. Dense aggregate blocks have a density in the range 1800 – 2100 kg/m^3, while lightweight aggregate blocks have with a density in the range 650 – 1600 kg/m^3. Aircrete

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blocks have a density in the range 400 – 900 kg/m^3 (Hamza and Yusuf, 2009).

Sandcrete blocks are generally defined as a mixture of sand, cement and water formed in a block making mould. The blocks are supposed to have adequate compaction pressure so that they can be confidently used in building of walls and other structures at various levels during construction (Nambiar and Ramamuurthy, 2008). Sandcrete blocks must satisfy building specification byelaws with respect to the compressive strength. The thickness of the blocks ranges from 50-255mm. The range of strength for sandcrete blocks specified by NIS 74:1976 is between 1.8N/mm^2 to 2.5N/mm^2 as the minimum strength. Falade, *et al,* (2012) found out that the compressive strength of sancrete blocks increased with age of curing for all mixes tested at the water cement ratio of 0.5. Falade, *et al,* (2011) also stated that the strength at ages 7, 14 and 21 days were 43%, 75% and 92% of the 28 days strength respectively.

Lightweight foamed concrete has been used around the world since 1920 with the compressive strength not critical but limited application (Nayak and Jain, 2012). It is referred to a premixed cement paste or mortar with minimum volume of 20% air voids entrapped in the mortar by using appropriate foaming agent (Awang *et al*, 2012). Lightweight foamed concrete has its advantages in high flowability, low self-weight, minimal consumption of aggregate, self-compaction, controlled strength and excellent thermal insulation properties (Ramamurthy *et al*, 2009). The density of lightweight foamed concrete is governed by the quantity of pre-formed foam. With proper control in amount of stable foam and methods of fabrication, a wide range of densities of lightweight foamed concrete could be formed and hence providing load bearing and non-load bearing masonry wall unit in building construction. Furthermore, lightweight foamed concrete also facilitates the benefits of self-levelling, where compaction or vibration is not required during concrete casting work.

These foam concrete materials basically consist of Portland cement, fine aggregate, water and stable foam. By adding materials such as stable foam, small cell or air bubble will form inside the concrete which is one of the factors that makes it lighter (Lim *et al*, 2013). It is also can be call homogeneous void structure, this process results from introducing air in form of bubble where this action incorporates small enclosed air bubbles within the mortar there by making concrete lighter than a normal concrete. The entrapped air bubbles increases volume and thereby reduces densities of a concrete (Dhir and Jones, 2009). The density of foam concrete is determined by amount of foam and water that added to the mixture.

3 Materials and Methods

3.1 Materials

The following materials were used in producing the lightweight foam sandcrete solid block used in this research work:

Cement: Ordinary Portland cement (OPC) – Dangote Portland Cement brands which conformed to NIS 444 – 1: 2003 as evidenced by the certification mark ISO 9001: 2008 on the product bags were used.

Water: Portable water which is free from suspended particles, salts and oil contamination were used throughout this study as specified by BS EN 12350 (2000).

Fly Ash: In this study, for the production of foamed light weight sandcrete block, fly ash is used which is collected from old Itori thermal power station.

Foam: A protein-based foaming agent, Lithofoam SL 200L, was used for this work. To produce the required foam concentration and to mix the sandcrete, clean and potable water was used. The ratios of foam concentrate to water adopted for this work was 1:25; the quantity of foaming agent being kept constant at 100g for all mixes. It is thoroughly mix with machine operated stirrer to achieve a stable foam.

Sand: Clean sand was used as fine aggregate, free from waste stone and impurities. The sand used for this work was taken directly from River Ogun at Ojere, Abeokuta in Ogun State of Nigeria. Particles passing through sieve size 2.36mm but retained on sieve size with 0.150mm aperture in accordance with BS 882: (1992) were used. This is because coarser aggregate might settle in a lightweight mix and lead to collapse of the foam during mixing.

3.2 Methods

3.2.1 Mix Proportions

Concrete mix design is the manner of selecting suitable constituents of concrete and determining the relative amount of the materials with the objective of producing the most economical concrete while holding the specified minimum properties such as strength, consistency and durability. There is no standard method of for proportioning the foamed light weight concrete like conventional concrete. From the literatures reviewed, it is quite significant that the density is the prime factor to be considered for manufacturing the cellular light weight concrete. The properties of cellular light weight concrete are directly or indirectly related to its density, such as the strength of the foamed light weight concrete decreases exponentially with the reduction in its density. Thermal and sound insulation is increased with the reduction in density. There are also some other factors like cement filler ratio and foam percentage, which indirect effects the density of the concrete. So that the density is prime concern for the production of foamed light weight concrete rather than target mean strength in conventional concrete. Six trail mix is casted with target density of approximately 1500 kg/m^3. It was on the basis of the results from trial mixes that the following mix design parameters were adopted:

i. Cement /sand (Sand and Fly-ash) ratio of 1: 6 (Conventional mix proportion for sandcrete block production)

ii. Water/Cement ratio of 0.5
iii. Foaming agent dilution of 1: 25

The details of mix proportion for foamed sandcrete solid block (FSSB) are given in Table 1.

Table 1. Mix Proportion for Foamed Sandcrete Solid Block

Cement (kg)	Sand (kg)	Fly-Ash kg	Fly-Ash % replacement
15	90	0	0%
15	81	9	10%
15	72	18	20%
15	63	27	30%
15	54	36	40%
15	45	45	50%

3.2.2 Curing

Water sprinkling curing was employed to maintain satisfactory moisture content and allow proper hydration and hardening of the foamed sandcrete solid blocks. The blocks were cured for the whole period of the 28 days during which they were tested at interval of 7days, 14 days and 28 days for their compressive strengths.

3.2.3 Workability Test

The slump test was carried out in accordance with the provisions of BS EN 12350 Part 2: (2000).

3.2.4 Wet Density Test

The wet density of the foamed concrete was determined according to the BS EN 12350: Part 6 (2000). The wet density of the foamed concrete was determined from the weight of a fresh sample in a container of known volume and weight for each of the batches before it was cast in mould. The density was then calculated by dividing the difference in the weight of concrete filled container and the weight of the empty container by the volume of the container.

3.2.5 Water Absorption Test

The water absorption capacity of the foamed concrete was determined according to the BS EN 12350: Part 3 (2000). The test specimens were completely immersed in water at room temperature for 24 hours. The samples were taken out from the water and wiped it. The sample was allowed for surface drying and the weight was measured. The same sample was placed inside an oven under the 100^{0}C of temperature for not less than 24hrs and until two successive weighing at intervals of 2hours show an increments of loss not greater than 0.2 percent of the last previously determined mass of the specimen (Nayak and Jain, 2012).

3.2.6 Compressive Strength

The compressive strength test was performed in accordance to BS EN 12390-3, by using a universal compression test machine with constant loading rate. 150 × 150 × 150 mm dimension were tested. The compressive strength was obtained based on the average of three crush FSSB specimens. The Compressive strength tests were carried out at 7, 14, and 28 days of moulding the foamed sandcrete solid blocks (FSSB) using ELE2000KN compressive testing machine. All tests were carried out at the Concrete Laboratory of the Moshood Abiola Polytechnic, Abeokuta, Nigeria.

4 RESULTS AND DISCUSSIONS

4.1 THE PROPERTIES OF THE SAND

From the results, the grading performed on the sand and the properties are: Specific gravity of fly-ash was 2.13; Specific gravity of sand was 2.65; Coefficient of uniformity (Cu) of sand was 1.92; Coefficient of curvature (Cc) of sand was 1.14; Fineness modulus of sand was 2.18. All these results showed that the sand is fine and suitable enough for the production of foamed sandcrete solid block (Ikponmwosa, *et al*, 2015).

4.2 WORKABILITY

The slump test carried out in accordance with BS EN 12390-3, showed that the average value of slump for the specimens tested was 45 mm. At this slump, the material still maintain its self-compacting properties, so that no compaction was needed for all the specimens produced and tested in this investigations. This also agrees with Falade, *et al*, (2012) that concrete with slump of between 25 and 50mm requires no compaction by vibration.

4.3 WET DENSITY

The effect of fly-ash on the density of the foamed sandcrete is shown in Figure 1. It shows that density decreases with increasing content of fly-ash. In relation to the control specimens, the decreased in wet density are 6.1%, 2.7%, 1.1%, 1.8%and 1.4% respectively for 10%, 20%, 30%, 40% and 50% sand replacement with fly-ash as shown in Table 2. This trend can be attributed to the fact that the specific gravity of sand is 2.65 and that of fly-ash is 2.13.

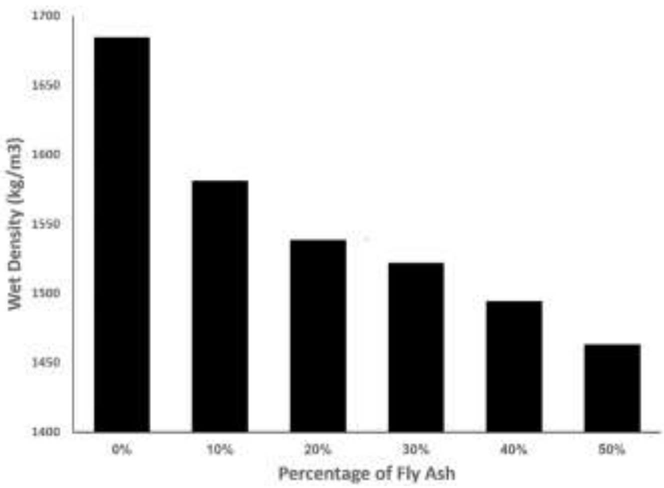

Fig.1: Effect of Fly-Ash on Wet Density of FSSB

4.4 STABILITY

Stability indicates the ability of the foam to go through the whole production process without collapse (Falade, *et al*, 2012). It is the ratio of wet density to design density. For stability, this value must tend towards one. The ratios obtained for different percentages of fly-ash are presented in Table 2, where the results show that stability is achieved at all levels of cement replacement with pulverized bone with the ratio revolving around unity. Thus the inclusion of fly-ash up to 50% of sand did not reduce the stability of the mix. The value of density was within the acceptable tolerance, and the coefficient of variability of less than 10% was also an indication of the satisfactory repeatability of production process (Jones, 2000). The designed density of this study is 1500kg/m³ as specified by Khaw, (2010).

$$Stability=\frac{Wet\ Density}{Design\ Density} \quad (1)$$

Table 2. Effect of Fly-Ash on Stability of FSSB

% of Fly-Ash	Wet density (kg/m³)	Design Density (kg/m³)	Stability
0%	1684.7	1500	1.06
10%	1581.4	1500	1.04
20%	1538.7	1500	1.03
30%	1522.1	1500	1.01
40%	1494.5	1500	1.00
50%	1463.4	1500	0.98

4.5 Dry Density

The average dry density at 28 day of Foamed Cement Solid Block with 1:6 mix ratio and varying percentage of sand replacement with fly-ash is shown in Table 3. The results show appreciable decrease in weight as compared with conventional sandcrete solid block which gives 1950kg/mm3. FSSB with 0% fly-ash has heaviest density of 1625.4kg/mm3, while FSSB with 50% sand replacement with fly-ash has lowest density with 1411.8kg/m³.

The effects of fly ash on dry density of the foamed sandcrete are shown in Figures 2. It can be seen that increase in the fly-ash content in the mix resulted in decrease in the dry density at all the curing ages for the specimens. For example, at 28-day curing age, the densities are 1585.4kg/m³, 1533.1kg/m³, 1497.8kg/m³, 1468.1kg/m³, 1432.3kg/m³, and 1411.8kg/m³ for 0%, 10%, 20%, 30%, 40% and 50% sand replacement with fly ash respectively. This trend was also observed for all curing ages among all specimens as shown in Figure 2.

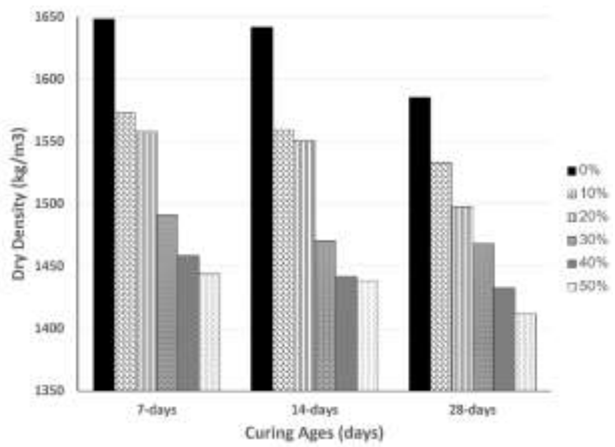

Fig. 2: Effects of Fly Ash on Dry Density of FSSB

Table 3. Average Dry Density of Varying Percentage of Sand Replacement with Fly-Ash

% of Fly Ash	7-days (kg/mm³)	14-days (kg/mm³)	28-days (kg/mm³)
0%	1648.2	1641.7	1585.4
10%	1572.7	1559.5	1533.1
20%	1557.9	1550.2	1497.8
30%	1491.2	1470.4	1468.1
40%	1458.7	1441.7	1432.3
50%	1443.6	1438.6	1411.8

This behaviour can be explained from the fact that the fly ash has lower specific gravity value than sand. Lower specific gravity has been found to result in lower density (Terzagi et al 1996) Thus, increasing the replacement levels has the effect of making the resulting concrete lighter. Also for each of the percentage replacement of sand with fly ash, the dry density decrease with curing age, but in a non-linear manner. A typical line graph Figure 3 showing Effect of sand replacement with fly ash for all specimens

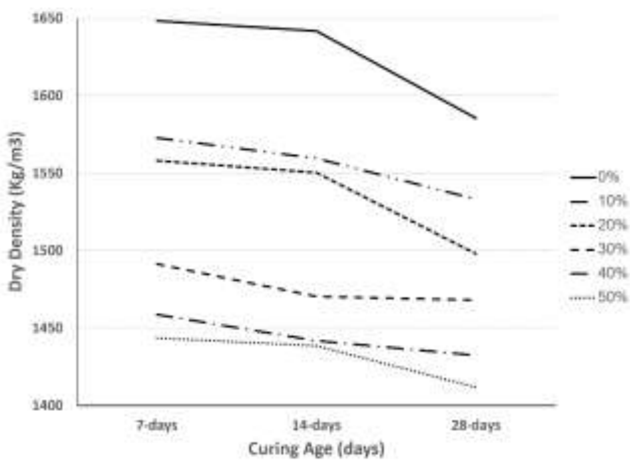

Fig. 3: Effect of sand replacement with fly ash for all specimens

4.6 Water Absorption

The average water absorption of FSSB manufactured with varying percentage fly ash replacement is shown in Table 4. It can be seen from the table that the water absorption decreases with increase in fly ash content. However, all varying mix proportion of FSSB which were considered for the study have acceptable value of 12% for masonry blocks according to BS 5628: Part 1: 2005. The variation of water absorption with varying percentage of fly ash content is shown in Figure 4. It can be seen that the water absorption is also maximum at highest percentage of fly ash content (50% of fly ash is 9.18% water absorption). But there wasn't significant difference with other varying fly ash content. With the increasing of fly ash content, the water absorption decreases.

Table 4. Water Absorption at varying percentage of Fly-Ash

% of Fly Ash	Average water Absorption (%)
0%	11.73
10%	10.76
20%	10.47
30%	9.81
40%	9.52
50%	9.18

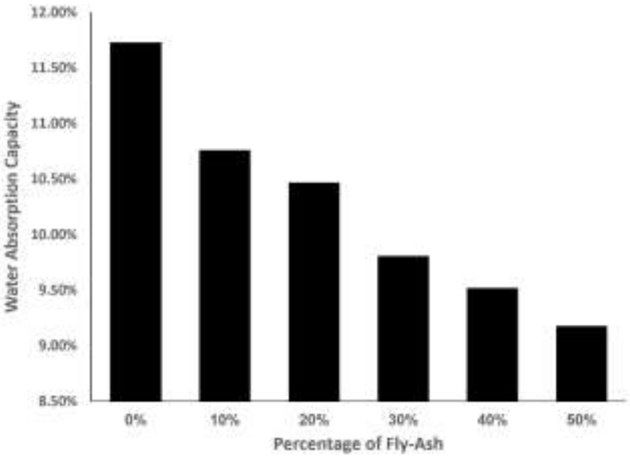

Fig. 4: Water Absorption at varying percentage of Fly-Ash

4.7 COMPRESSIVE STRENGTH

Result of compressive strength test of FSSB is given in Table 5. Introduction of fly-ash as replacement of sand in FSSB proportion decreases the compressive strength of FSSB. Compressive strength decreases as fly ash content in proportion increases. With 0% fly ash in the mix, it gives compressive strength of 3.74N/mm² after 28 days of curing, with 50% fly ash in the mix, it possess 2.77N/mm² of compressive strength after 28 days of curing as presented in Table 5.

Table 5. Compressive Strength and Percentage Variation of Test Specimen

% of Fly Ash	7-days (N/mm²)	1 4-days (N/mm²)	28-days (N/mm²)
0%	3.37	3.53	3.74
10%	2.91 (13.65%)	3.07 (13.03%)	3.17 (15.24%)
20%	2.66 (8.59%)	2.85 (7.17%)	2.98 (5.99%)
30%	2.49 (6.39%)	2.66 (6.67%)	2.91 (2.35%)
40%	2.32 (6.83%)	2.47 (7.14%)	2.83 (2.75%)
50%	2.25 (3.02%)	2.38 (3.64%)	2.77 (2.12%)

4.7.1 Effect of Curing Age on Compressive Strength Development

Figure 5 presents variation of the compressive strength with curing age. The figures show that compressive strength of foamed sandcrete at the designed density of 1500kg/mm³ used for this study increased with curing age for all the specimens at all the replacement levels. This is an indication of the production of the strength-forming C-S-H gel as a result of cement hydration with curing age. For the control specimens (0% fly ash) the 7-day strengths is 3.37N/mm² and 2.25N/mm² for 50% fly ash at 7-day curing; and the 28-day strength are 3.74N/mm² and 2.77N/mm² for both 0% and 50% fly ash content in the specimens respectively. These represent increases in strengths of 9.89% and 18.77% for both 0% and 50% fly ash content respectively.

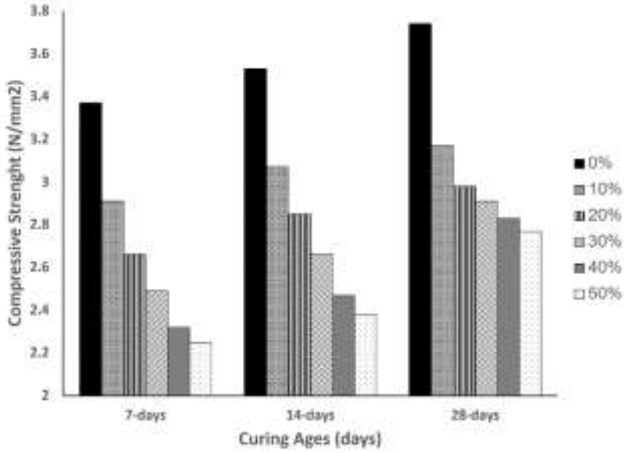

Fig. 5: Variation of the Compressive Strength with Curing Age

4.7.2 Effect of Fly Ash on FSSB on Compressive Strength

In this study, all the specimens containing partial replacement of sand with fly ash developed lower strengths when compared with the control specimens at all the curing ages for the specimens. From Figure 6, at 7-day curing age, the strengths are 3.37N/mm², 2.91N/mm², 2.66N/mm², 2.49N/mm², 2.32N/mm² and 2.25N/mm² for 0%, 10%, 20%, 30%, 40% and 50% sand replacement with fly ash respectively. This represent 13.65%, 8.59%, 6.39%, 6.83%, and 3.02% reduction in strength from the control; for 10%, 20%, 30%, 40% and 50% sand replacement with fly ash respectively. The trend of percentage variation was also observed for 14-day and 28-day strengths specimens as shown in Table 5. From the results, it is noted that the strength reduction is highly significant between 0% and 10% sand replacement with fly ash, with sharp slope indication on figure 6. However, the strength reduction is moderately significant between 10%, 20% 30 and 40%, and less significant between 40% and 50% sand replacement with fly ash, with virtually flat slope indication, especially with 28-day curing age. The 2.77 N/mm² compressive strength value for 50% replacement levels still qualified the foamed Sandcrete solid block used for this investigation to be classified as non-load bearing solid block (BS EN 12390-3. 2009).

4.7.3 Comparison of Compressive Strength with Dry Density

Table 6 shows the relationship between the compressive strength and the dry density at a curing age of 28-day, while the relationship between the compressive strength and water absorption at a curing age of 28-day is presented in Table 7.

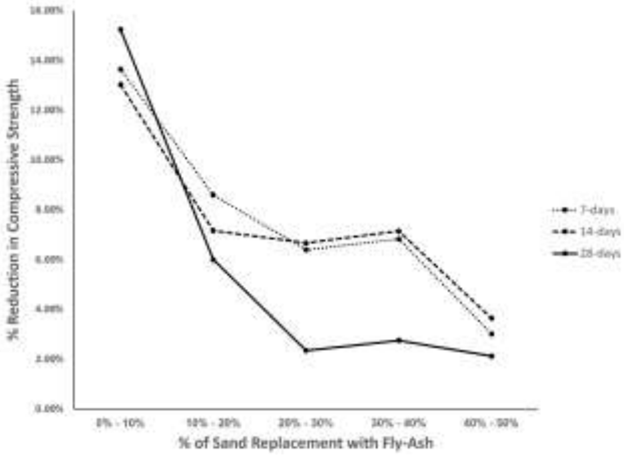

Fig. 6: Percentage Reduction in Compressive Strength with fly-ash replacement

Table 6. Comparison between Compressive Strength and dry density

% of Fly Ash	Dry density, d	Compressive Strength, f_c	Ratio (%), f_c/d
0%	1585.4	3.74	0.24%
10%	1533.1	3.17	0.21%
20%	1497.8	2.98	0.20%
30%	1468.1	2.91	0.20%
40%	1432.3	2.83	0.20%
50%	1411.8	2.77	0.20%

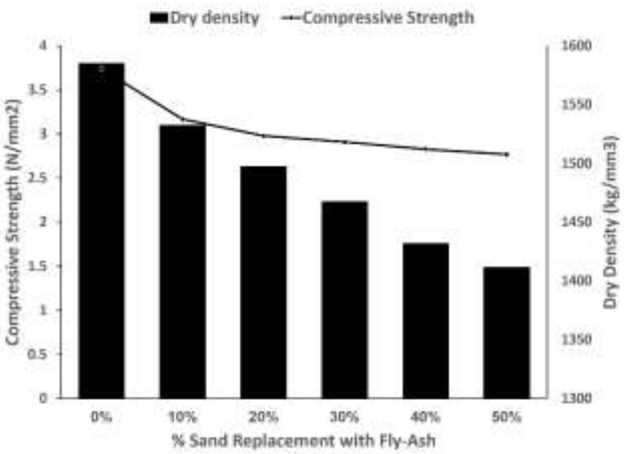

Fig.7: Combined Result of Compressive Strength and Dry Density

The dry density varies between 0.20% and 0.24% of the compressive strength and the ratio decreases with increase in percentage sand replacement with fly-ash. Figure 7, shows combined result of dry density and compressive strength carried out in this study. Using the statistical line of best fit, and with linear regression analysis, this relationship can be represented as:

$$f_c = 0.0057d - 5.38 \quad (2)$$

where f_c = Compressive strength and d = dry density

Table 7. Comparison between Compressive Strength and Water Absorption

% of Fly Ash	Water Absorption, w	Compressive Strength, f_c	Ratio (%), f_c/w
0%	11.73	3.74	31.88%
10%	10.76	3.17	29.46%
20%	10.47	2.98	28.47%
30%	9.81	2.91	29.66%
40%	9.52	2.83	29.72%
50%	9.18	2.77	30.17%

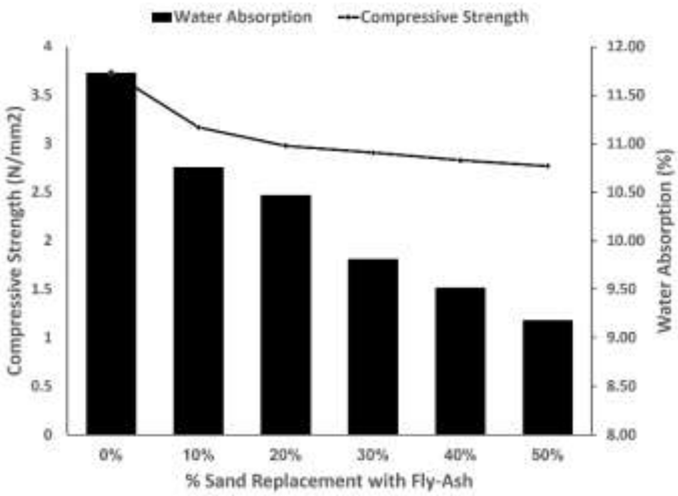

Fig.8: Combined Result of Compressive Strength and Water Absorption

It is also observed that water absorption capacity varies between 28.47% and 31.88% of the compressive strength and the ratio appeared in a scattered manner with increase in percentage sand replacement with fly-ash. Figure 8, shows combined result of water absorption capacity and compressive strength carried out in this study. Using the statistical line of best fit, and with linear regression analysis, this relationship can also be represented as:

$$f_c = 0.474w - 1.717 \quad (3)$$

where f_c = Compressive strength and w = water absorption capacity

These expressions are valid for the percentage sand replacement with fly-ash used in this experimental study for foamed sandcrete solid block (FSSB)

5 CONCLUSION

The paper contains a study of properties of Foamed Sandcrete solid block and also the utilization of sand replacement with fly-ash in the proportion of FSSB. From the result of this investigation, several conclusions can be drawn from the experimental study:

1. The 28-day compressive strength of 2.77N/mm^2 obtained from 50% sand replacement with fly-ash at the designed density of 1500kg/m3 meets the minimum strength requirement for classification as a non-load bearing wall unit. It falls between 2.5N/mm^2 and 3.45N/mm^2 as recommended by Nigerian Industrial Standard (NIS).

2. Lightweight foamed sandcrete solid block (FSSB) with density of 1411kg/m3 was achieved with 50% sand replacement with fly-ash at a curing age 0f 28-day, which is less than 1600kg/m^3 as recommended by Nigerian Industrial Standard (NIS).
3. Lightweight foamed sandcrete solid block (FSSB) with water absorption capacity of 9.18% was achieved with 50% sand replacement with fly-ash at a curing age of 28-day, which is less than 12% recommended as water absorption capacity by NIS.
4. The use of fly-ash in the production of foamed sandcrete solid block will help to clean the environment of potentially hazardous wastes, and reduction in consumption of non-renewable resources.
5. Compressive Strength of the FSSB is decreased when sand is partially replaced by fly ash content in it.
6. The percentage reduction is very low, and less significant at curing age of 28-day between 30%-50% sand replacement with fly ash

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